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The thermal resistance of a winter tent

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Abstract

The primary shelters used by Canadian infantry units in winter are the 5 and 10-man arctic tents. The thermal insulation of a 5-man tent was measured in an environmental chamber, by a new method, using a thermal manikin. A variable amount of heat was added to the interior of the tent with electrical heaters to increase the sensitivity of the method. The contribution of the liner to the total insulation was then easily detected. The method will be useful in comparing tents for cold weather and for assessing the effects of design changes.

Résumé

Les principaux abris utilisés par les unités d'infanterie canadiennes en hiver sont les tentes arctiques pour cinq et pour dix personnes. L'isolation thermique d'une tente pour cinq personnes a été mesurée dans une enceinte à atmosphère contrôlée, à l'aide d'une nouvelle méthode faisant appel à un mannequin thermique. Une quantité variable de chaleur a été ajoutée à l'intérieur de la tente au moyen d'appareils de chauffage électriques afin d'accroître la sensibilité de la méthode. L'apport de la doublure à l'isolation totale a ensuite pu être facilement déterminé. La méthode sera utile pour comparer des tentes destinées à être utilisées par temps froid et pour évaluer l'incidence des modifications apportées à la conception.

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Executive summary

The primary shelters used by Canadian infantry units in winter are the 5 and 10-man arctic tents. The thermal insulation of a 5-man tent was measured in an environmental chamber, using a thermal manikin. Because the insulation value of a large tent is small and its surface area is large compared to a manikin, manikin heat loss is only a little different in a large tent than it would be without the tent, at least in still air. The effect of the insulation of the tent on the manikin heat loss was amplified by adding a large amount of heat to the inside of the tent when the manikin was operating. This greatly and reproducibly increased the sensitivity of the method. Experiments were carried out with a complete tent and with the same tent after removing its liner. The contribution of the air space between the tent and the very air permeable liner was only half as effective as insulation as the tent itself. This difference was easily detected. The method will be useful in comparing tents for cold weather and for assessing the effects of design changes.

Osczevski, R. J. 2004. The Thermal Resistance of a Winter Tent. TR 2004-179 DRDC-Toronto.

Sommaire

Les principaux abris utilisés par les unités d'infanterie canadiennes en hiver sont les tentes arctiques pour cinq et pour dix personnes. L'isolation thermique d'une tente pour cinq personnes a été mesurée dans une enceinte à atmosphère contrôlée, au moyen d'un mannequin thermique. Étant donné que l'indice d'isolation d'une grande tente est faible et que sa superficie est vaste par rapport au mannequin, la perte de chaleur de ce dernier dans une grande tente ne diffère que légèrement de celle qui se produirait sans la tente, du moins par vent nul. On a augmenté l'incidence de l'isolation de la tente sur la perte de chaleur du mannequin en ajoutant une quantité importante de chaleur à l'intérieur de la tente quand le mannequin était sollicité, ce qui a accru grandement et de façon répétitive la sensibilité de la méthode. On a effectué des expériences à partir d'une tente avec la doublure, puis à partir de la même tente, mais sans la doublure. En tant qu'isolant, la couche d'air entre la tente et la doublure hautement perméable à l'air était deux fois moins efficace que la tente elle-même. Cette différence a été repérée facilement. La méthode sera utile pour comparer des tentes destinées à être utilisées par temps froid et pour évaluer l'incidence des modifications apportées à la conception.

Randall J. Osczevski. 2004. Résistance thermique d'une tente d'hiver. TR 2004-179 DRDC Toronto.

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Introduction

The primary shelter used by Canadian infantry units in winter is the 10-Man Arctic Tent. This is a five-sided fabric shelter with an internal fabric lining, supported by a central tent pole. The 5-Man Arctic Tent is a scaled-down version of the bigger tent, in the same materials. When heated by open-flame camp stoves and lantern, the temperature of the air in a heated tent is vertically stratified, with very high temperatures near the peak – as high as 60 °C above the temperature at sleeping bag level, which may be well below freezing (1). The temperatures of the internal walls of the tent also vary widely. As a result, there is a complex environment for free convective and radiative heat transfer.

To determine the "insulation value" of the tent, it is only necessary to measure the mean temperature difference that is set up when a known amount of heat power is applied to the interior. However, this is not as easy as it sounds because it is difficult to determine a relevant value of the mean internal temperature of the tent. While it is possible, if laborious, to measure dozens of temperatures to approximately characterize the microenvironment of the tent, the question that would remain is how to weight all these temperatures so that the resulting weighted mean is relevant to the heat loss of an individual sitting in its lower regions. For instance, how much weight should be given to the high peak temperature; how might the large vertical temperature gradient affect free convective cooling from bare skin, and how would the temperatures of the walls and floor and ceiling affect his or her radiative cooling rate?

One could attempt to mathematically model all convective and radiative exchanges, but there is a much simpler approach. This report describes a highly reproducible way to determine the effective insulation value and mean internal temperature of a tent. With this method, which uses a thermal manikin, not a single tent temperature need be measured and no weighting factors have to be explicitly assigned for they are implicit in the measurement. These two factors can be can be used to quantify the differences between different tents, or the effects of changes in tent design, heating methods or materials on the microclimate.

Theory and Equations

A thermal manikin is an instrument designed to simulate a human body for measurements of the thermal resistance (insulation) of clothing (2). Its outer surface is usually a thermally conductive metal "skin" in which electrical heaters are imbedded. The electrical power delivered to these heaters is controlled by a computer, which senses the "skin" temperature and adjusts it to a constant value by varying the voltage applied across the heater resistances. When the temperatures are constant, the electrical power applied to the heaters is equal to the heat loss from the surface of the manikin. The difference between the set surface temperature and ambient temperature, divided by the heat loss per unit area of the manikin is the insulation value of the clothing worn by the manikin.

While in theory it is possible to measure the thermal insulation added to a thermal manikin by surrounding it with a tent, in practice, it is not so simple. If you put a thermal manikin in a tent in relatively still air and turn it on, its heat loss rate hardly differs from what it would be without a tent. A large tent has such a large surface area compared to a manikin that the small amount of heat the manikin loses does little to warm the vast interior, making difficult to detect any change in insulation added by the tent.

However, if a large amount of heat is added to the tent by heaters external to the thermal manikin, the internal tent temperature is directly related to the insulation of the tent. The effective temperature to which the manikin is exposed determines its steady state heat loss rate. There will, therefore, be a relationship between the tent thermal resistance and the heat loss rate of a manikin in a heated tent.

The rate of heat loss from the tent to the environment is given by:

$$Q_{tent} = Q_{manikin} + Q_{heaters} = \frac{(\overline{T}_{tent} - T_{ambient})}{R_{tent} / A_{tent}} \qquad [1]$$

where R_{tent} / A_{tent} is the ratio of the thermal resistance of the tent to its surface area for heat loss and $\overline{T}_{tent}$ is the effective mean internal temperature of the tent. At steady state, Q_{tent} is the sum of the heat loss of the manikin and the power used by the auxilliary heater. The rate at which the manikin loses heat is:

$$Q_{manikin} = \frac{(T_{manikin} - \overline{T}_{tent})}{R_{manikin} / A_{manikin}} \qquad [2]$$

where $R_{manikin}$ is the thermal resistance measured by the manikin, which is a function of the amount of air movement in the tent, the free convection and radiant heat exchange, and $A_{manikin}$ is its surface area. For simplicity, the manikin is bare. Assuming that $\overline{T}_{tent}$ is the same in each case, these equations may be solved to yield:

$$Q_{manikin} = -\frac{R_{tent} A_{manikin}}{R_{manikin} A_{tent}} Q_{tent} + \frac{(T_{manikin} - T_{ambient})}{R_{manikin} / A_{manikin}} \qquad [3]$$

Equation [3] has the form y = mx+b, where y is the manikin heat loss rate and x is the heat loss from the whole tent. This is the equation of a straight line. If we do an experiment in which the rate of heat loss of a thermal manikin is measured at various heater powers, a graph of $Q_{manikin}$ vs. Q_{tent} should be a straight line. The intercept (b) is the heat loss of the manikin when no heat is added to the tent by the heaters. The thermal resistance of the tent may be expressed in terms of the slope (m) and intercept of the line:

$$\frac{R_{tent}}{A_{tent}} = I_{tent} = \frac{-m}{b}(T_{manikin} - T_{ambient}) \qquad [4]$$

In practice, Q_{tent} may be assumed to be approximately equal to the electrical energy used by the auxiliary heaters as it is much greater than the manikin heat loss. The insulation value of the tent, I_{tent}, is the ratio of the thermal resistance of a unit area of the tent to its total surface area, $\frac{R_{tent}}{A_{tent}}$. This is the thermal insulation of the whole tent, as experienced by the thermal manikin. It has units of K/kW, i.e. °C above ambient temperature per kilowatt of power added by tent heaters.

The effective internal tent temperature is then just:

$$\bar{T}_{tent} = T_{ambient} + I_{tent} \times Q_{heaters} \qquad [5]$$

Experimental Validation

Materials and Methods

A tent of the same design as the standard 5-Man arctic tent was set up in an environmental chamber. The major difference between this tent and the standard one was the fabric, which was printed in CADPAT camouflage on a shower proof nylon/cotton fabric of approximately the same weight as the in-service nylon/cotton tent fabric.

Figure 1. DRDC-Toronto Thermal Manikin Head

Electrical blower heaters were used as heat sources to simulate open flame combustion stoves (Masterflow Heat Blower AH301, Master Appliances, 120 VAC 10A). The stoves were arranged in a triangle around the centre of the tent floor with the intakes pointed radially away from the tent pole. The fan motors and resistance heaters were rewired so that they were powered separately. The fans of all three heaters were always running so that the air movement in the tent was constant regardless of how many heaters were being used to produce heat.

DRDC-Toronto Thermal Manikin Head (2) (TMH) was used in the experiment (Fig. 1). The surface of this device is divided into five separate zones from which the rate of heat loss may be separately determined. The average surface temperature of each section is maintained at a constant temperature by a computer, which senses the temperature of each section. To minimize heat transfer between sections, their surface temperatures are kept within 0.02 °C of each other. The fifth section, the neck, prevents axial heat transfer downwards. The TMH was positioned facing the centre, with its nose 0.75 m from the tent pole, on a line between the middle of the second wall to the right of the door and at a height of 0.70 m.

Figure 2 is a sample of the measurements made by the manikin head. The stepped reduction in manikin head heat loss occurred when approximately1 kW of electrical power was applied to one of the tent heater/blowers.

Results

Figure 3 illustrates the straight-line relationships between manikin head heat loss rate and the amount of heat added to the tent. The slope of each line and the y-intercept were used in equation 4 to calculate the thermal resistances in Table 1.

Table 1. Thermal insulation of a 5-man tent

	T ambient [°C]	T manikin [°C]	m	b [W]	I_{tent} [°C/kW]
Tent and Liner	-18.5	30	-0.0144	53.1	13.2
Tent and Liner	-14.7	30	-0.0146	49.7	13.1
Tent Only	-14.7	30	-0.00978	49.7	8.80
Tent Only	-14.7	25	-0.0098	43.2	9.01
Tent Only	-10.5	25	-0.0095	38.5	8.76

As Table 1 shows, even when the ambient and manikin surface temperatures were varied, the method produced consistent results.

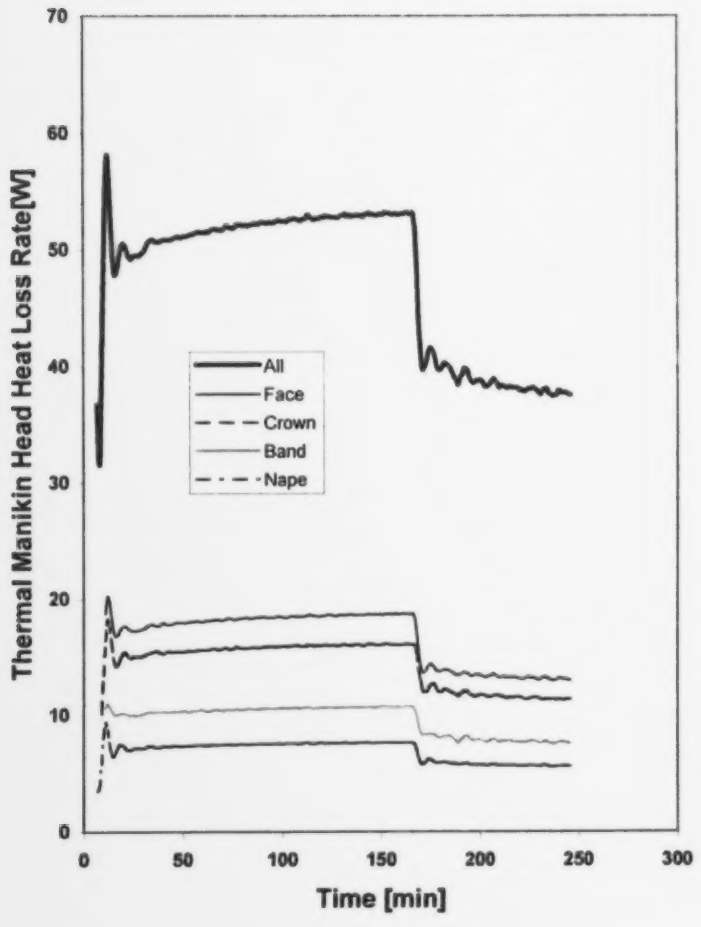

Figure 2. Heat loss from the thermal manikin head with a 1 kW step increase in heater power; head surface temperature 30 °C, chamber temperature –18.5 °C.

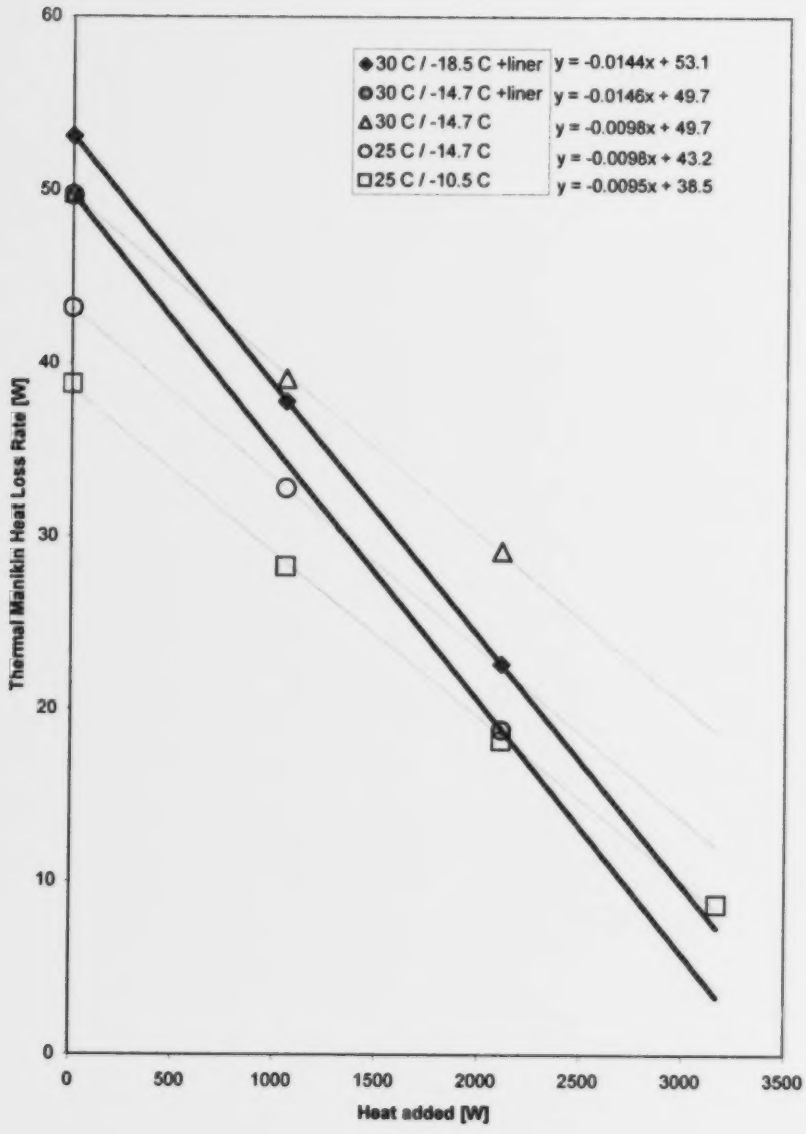

Figure 3. Comparison of 5-man tent experiments at various ambient and manikin head temperatures. The first temperature in the legend is the manikin head surface temperature; the second is the chamber temperature. Lines are parallel for each configuration. Slopes and intercepts from these lines were used in equation 4 to calculate the insulation values of the tent in Table 1.

Discussion

The tent alone has an insulation value of 8.9 °C per kilowatt of heating. Adding a porous liner had an easily detectable effect on the protective value of the tent. The liner added 4.2 °C for each kilowatt of heater power and was therefore, only about half as effective as the tent on its own.

The area for heat loss was about 9.5 m^2. The average thermal resistance of a unit area of tent, liner and enclosed air space was therefore 0.124 m^2K/W, which is not impressive as it is equivalent to little more than a single boundary layer on a heated surface in still air. The boundary layers on both sides of the quite permeable liner were probably affected by air movement created by natural convection or by the forced air from heater/blowers. The flow rate of the fans will be reduced in subsequent experiments. It would be interesting to determine the affect of liner permeability on its contribution to the insulation value of the tent. In the past, the liner was made of a far more windproof fabric.

From equation 5, at an ambient temperature of –30 °C, a 5-man tent with a two burner stove producing 4.0 kW of heat is predicted to have, at most, an effective interior temperature of +22 °C, which should be quite comfortable. Without a liner, the effective mean interior temperature would be about +3 C, which would not be very comfortable when sitting for an extended period of time.

The measurements that the above calculations are based on were carried out in a cold room with an insulated floor through which the heat loss rate was effectively zero. The additional heat loss through the floor of a heated tent pitched on snow over frozen ground would reduce the interior temperature, but by how much is not known.

The effective thermal insulation of a tent varies from place to place in its interior. The overall value calculated here applies strictly only to the head at sitting height. Local values nearer the floor may be more critical to the comfort and safety of individuals lying down, or to their feet while sitting.

Conclusion

The overall protective value of a large tent, at least at the level of the face of someone kneeling in the tent, may be precisely determined with this procedure. This method can be used to quantify the thermal effect of changes in the design of the tent and its liner.

References

1. Osczevski, R., G. Underwood, T. Oftedahl, (1977), Microclimate of a Ten-Man Arctic Tent, Defence Research Establishment Ottawa Technical Note 77-23.

2. DRDC Toronto (2002) *Thermal Manikin Head*, Fact Sheet T-18.

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14. ABSTRACT

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